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CAVITATION PERFORMANCE OF A PROPELLER DESIGN FOR A NAVAL AUXILIARY CILER (AO 177) (MODEL 5326 WITH DESIGN PROPELLER 4645)

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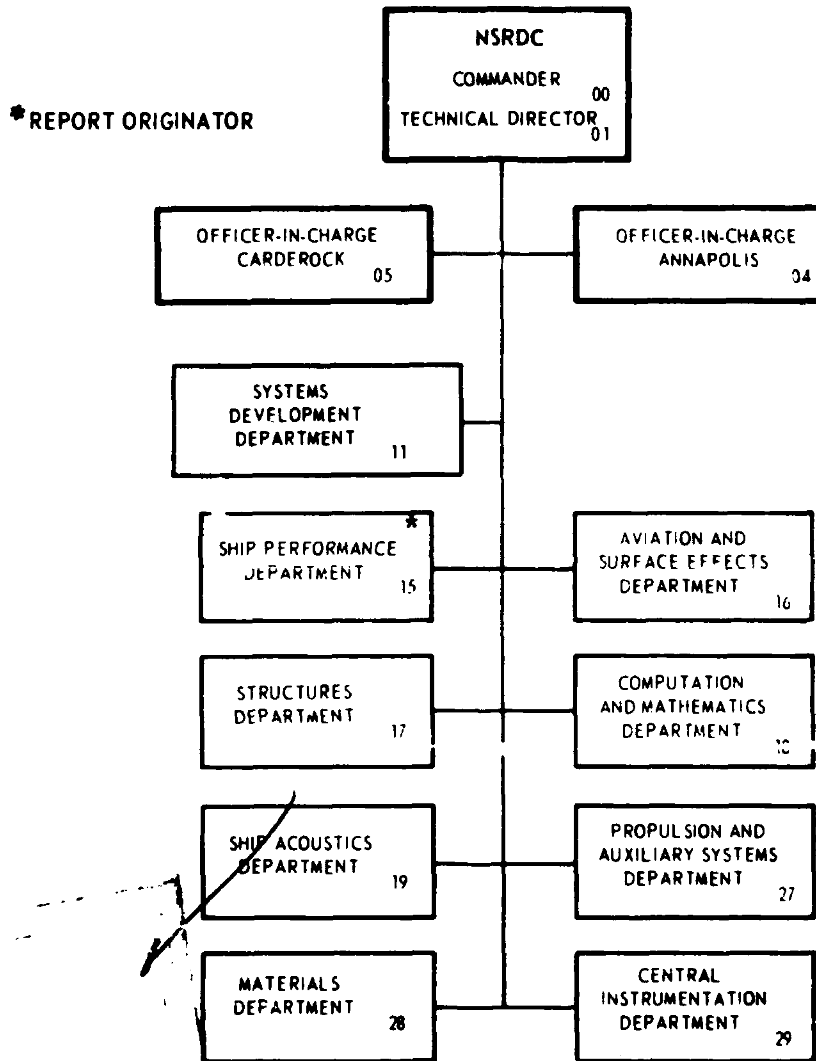

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Cavitation experiments were performed on a model propeller designed for (AO 177). The results showed satisfactory performance concerning power loss however a potential problem with erosion is predicted based on these results. Additional erosion studies are recommended.

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NOTATION

BTF	Blade thickness fraction
c	Propeller blade section length
$c_{0.7}$	Propeller blade section length at 0.7R
C_o	Maximum chordwise camber
C_A	Correlation Allowance
C_F	Frictional resistance coefficient, $R_F/1/2\ \rho V^2\ S$
C_R	Residuary resistance coefficient, $R_R/1/2\ \rho V^2\ S$
C_T	Total resistance coefficient, $R_T/1/2\ \rho V^2\ S$
D	Propeller diameter
EAR	Expanded area ratio, A_E/A_O
g	Acceleration due to gravity
H	Total head at shaft centerline, less vapor pressure
H_L	Total local head, less vapor pressure
J	Advance coefficient of propeller, V_A/nD
J_L	Advance coefficient of propeller, local wake, $\dfrac{V_X}{(nD) + \left(\dfrac{V_t}{(r/R)\pi}\right)}$
J_T	Advance coefficient based on thrust identity
J_V	Advance coefficient based on ship speed V/nD
K_Q	Torque coefficient $Q/\rho n^2\ D^5$
K_T	Thrust coefficient $T/\rho n^2\ D^4$

NOTATION
(continued)

n	Rate of revolution
P	Propeller pitch
P_E	Effective horsepower
P_S	Shaft horsepower
Q	Torque
R_n	Reynolds number for propeller, $\dfrac{c_{0.7}\sqrt{V_A^{\,2} + (0.7\ \pi nD)^2}}{\nu}$
R_F	Frictional resistance
R_R	Residuary resistance
R_T	Total resistance
r/R	Nondimensional propeller radius
S	Wetted surface
t	Thrust deduction fraction, $(T-R_T)/T$
t_m	Maximum chordwise thickness
T	Thrust
V	Ship speed
V_A	Propeller inflow velocity
V_t	Local tangential velocity
V_x	Local longitudinal velocity
w_T	Taylor wake fraction determined from thrust identity
w_Q	Taylor wake fraction determined from torque identity

NOTATION
(continued)

η_H	Hull efficiency
η_O	Propeller efficiency in open water
η_P	Propeller efficiency behind the hull
η_R	Relative rotative efficiency
η_S	Propulsive efficiency, P_E/P_S
θ_S	Projected skew angle
ν	Kinematic viscosity
ρ	Density
σ	Cavitation number based on vapor pressure, $2gH/V^2$
σ_L	Cavitation number based on vapor pressure, local wake and head, $2gH_L/V_X^2$

ADMINISTRATIVE INFORMATION

This work was performed at the Naval Ship Research and Development Center (NSRDC), Bethesda, Maryland 20084. The project was authorized by the Naval Ship Engineering Center (NAVSEC), ltr 6136C/DMC 9290, Ser 90, 17 May 1974, and was funded under Purchase Order 4-0118, Amendment 1, 17 April 1974, NSRDC Work Unit 1524-535.

INTRODUCTION

The Naval Ship Engineering Center initiated a physical model experimental program at NSRDC to aid in the evaluation of a design propeller for a Naval Auxiliary Oiler (AO).[1]

PROCEDURE AND RESULTS

The propeller evaluated, NSRDC Model Propeller 4645, was a fixed pitch, 9.812 inch diameter propeller which represents a 21 foot propeller full scale. Baseline experiments were conducted with stock Propeller 4572A which represented about a 23 foot diameter propeller. After a thorough investigation was performed at NSRDC, it was decided by NSRDC (Code 1544) and NAVSEC (Code 6144) to reduce the diameter from 23 feet to 21 feet. Details of the design of the AO-177 propeller can be found in Reference 2. A drawing of this propeller is presented in Figure 1. Table 1 gives the geometry of the propeller. This report presents the open-water and cavitation experimental evaluation for the propeller. The open-water experiment was performed to provide predictions of propeller performance for use in the propulsion experiments[3], and to calibrate tunnel velocity for the

*References are listed on page 7 .

cavitation experiment. The cavitation experiments were performed to determine the type and extent of propeller cavitation in order to predict its effect on ship powering and the possibility of blade erosion.

The open-water experiment was performed with the Center's standard propeller boat in the deep-water basin, using a one horsepower gravity type dynamometer. The experiment was performed at Reynolds Numbers greater than 5.0×10^5 to insure turbulent flow over the propeller blades. Thrust and torque were measured, while the rate of revolution was varied from 10.0 to 14.5 rps and velocity was varied from 5 to 12 fps. Velocity and rate of revolution were determined to within 0.01 fps and rps. Thrust and torque measurements were accurate to within $\pm$ 0.2 pounds or inch-pounds.

The cavitation experiments were conducted in the closed-jet test section of the Center's 24-inch Variable Pressure Water Tunnel in a nonuniform flow field produced by a wire grid. This wake screen, located 30 inches upstream of the propeller, was designed[4] to produce at the propeller the longitudinal wake components predicted from the wake survey behind the hull model. A plot of the longitudinal wake components which the screen was designed to produce is shown in Figure 2 compared to the AO-177 longitudinal wake. Figure 3 shows a photograph of the tunnel experimental set-up. The propeller was powered, and thrust and torque were measured by the 150-hp downstream dynamometer. Test section velocity, 14 fps, was calibrated for each advance coefficient (J) by using the thrust coefficients (K_T) from the open-water characteristics. The calibration was performed by setting the rate of revolution for the advance coefficient and adjusting the water speed until the thrust coefficient at the propeller disk was the same as the open-water thrust coefficient. This calibrated velocity was held constant and static pressure varied to change cavitation number.

The cavitation experiment were conducted over a range of cavitation numbers, (σ) from 15.3 to 1.9 while including ship speeds from 14 to 24 knots, based on a full-scale submergence of 21.49 feet to the shaft centerline. The experiment covered a range of advance coefficients from 0.7 to 1.2.

Thrust, torque, velocity, rate of revolution, and pressure were recorded during the experiment. The accuracy of measurements were: thrust, $\pm$ 0.5 pound; torque, $\pm$ 0.1 foot-pound; velocity, within 0.1 fps of the average test section velocity; rate of revolution, $\pm$ 0.01 rps; and static pressure, $\pm$ 0.01 inch of mercury. The air content of the tunnel water was held as nearly as possible at 30% of atmospheric saturation (measured by Van Slyke apparatus) in order to provide clear visibility throughout the cavitation number range. Water temperature varied from 96° to 108° Fahrenheit during the testing period.

DISCUSSION

Results of the open-water experiment are shown in Figure 4 and Table 2 in nondimensional coefficients of thrust (K_T), torque (K_Q), and efficiency (η_0) over a range of advance coefficients (J).

Results of the cavitation experiment are shown in Figure 5. All coefficients are based on velocity at the propeller. These curves are based on visual observations. The inception curve is based on the first condition, i.e., highest cavitation index and lowest advance coefficient (back cavitating)* and any circumferential position,at which cavitation of a particular type is observed. The area above any curve indicates that no cavitation of that type was visible at these conditions anywhere around the disk. Below the

*The observation would be highest advance coefficient for face cavitation.

curve the cavitation intensity increases with decreasing cavitation number. Also shown, are two curves based on propulsion data for correlation allowances of 0.0005 and 0.0012, adjusted for mean wake. Along these curves, ship speed is indicated in knots. Cavitation sketches are presented in Figures 6 through 8 showing observed cavitation for ship speeds of 20, 21, 21.5, 22 and 23 knots with $C_A = .0005$. These figures present cavitation sketches showing changes in cavitation intensity due to the nonuniform flow produced by the simulated model wake. The angles on the sketches indicate areas of from no cavitation to maximum cavitation and back to no cavitation. Figure 3 is a photograph of the typical cavitation patterns observed for ship speeds up to about 22 knots. This photo shows back cavitation as caused by the high wake region behind the hull. Tip vortex is weak. Back cavitation appears and disappears as the propeller blades pass through the high wake region behind the hull. This back cavitation must therefore form and collapse each cycle of the propeller through the wake. The photo shows a white mist as the cavity is collapsing which could be a potential erosion problem (discussed later). Hub vortices could not be evaluated due to the downstream driving experimental setup. Typical face and back bubble cavitation at off design conditions is shown in the photographs of Figure 9. Face cavitation in these conditions flashed on with tip vortex down to 0.8 radius near the leading edge and off the surface of the blade. Face cavitation was very noisy and could be heard before it was visible. Bubble cavitation inception was observed beyond the operating speed range. Large bubbles appeared near the leading edge and propagated up the midchord of the blades. These bubbles started just outside of the high wake region where no back and sheet cavitation had occurred and as the pressure was reduced, these bubbles entered into the sheet cavitation in the high wake region.

From Figure 5 the inception speed of various types of cavitation are predicted for $C_A = .0005$ below:

Type	Speed
Initial Back Sheet 0.95 R	~ 15 knots
Back Sheet 0.8 R	~ 20.7 knots
Back Bubble	> 22 knots
Face Sheet	does not intersect
Tip Vortex (uncorrected for Rn) (Back)	~ 15 knots
Tip Vortex (corrected for Rn)(Back)	~ 9.5 knots
Tip Vortex (uncorrected for Rn) (Face)	does not intersect
Tip Vortex (corrected for Rn) (Face)	~ 14.5 knots

Based on the data obtained and the inception speeds there is no measurable power loss due to cavitation.

Normally the type of cavitation observed is considered to present little problem in erosion. Sheet cavitation extending to about 0.75 radius at the extreme conditions as the propeller passes through the high wake region is typical of this type propeller. Upon removing the propeller after completion of the experiments (about 20 hours of tunnel running time), it was observed to have pitting of the anodized surface near the 0.9 radius trailing edge. Figure 10 shows photographs of the area mentioned. While no conclusive data is available, it has been observed in the past that after 40 hours of testing model propellers in the water tunnel, if no pitting of the anodizing is indicated, no erosion problems are likely. But, as in this case, if pitting is observed, there is a strong possibility that full scale erosion may be a potential problem. There is one mitigating circumstance which should be checked out. Due to a heavy test schedule at NSRDC the tunnel water temperature

reached 108° Fahrenheit. It is known that increasing temperature increases rate of erosion. B. W. Hansen and R. E. H. Rasmussen[5] show the erosion of aluminum specimens increases from 40° to at least 112° Fahrenheit due to cavitation. In the range of temperatures the tunnel experiments were performed (96° to 108°F), the increase in erosion rate over the normal temperatures of the tunnel water is about 17% as shown by Hansen. With an exposure of less than 50% of the normal safe no-erosion test and with a predicted 17% increase in erosion rate, it is predicted that there is a possibility of an erosion problem with this propeller. Hence, some additional erosion work should be performed to further evaluate the erosion problem.

REFERENCES

1. NAVSEC Revision No. 1 of "AO 177 Class Model Test Plan for Contract Design Phase," 22 April 197 .

2. Valentine, D. and Chase, A., "Highly Skewed Propeller Design for a Naval Auxiliary Oiler (AO-177)," NSRDC Report in Preparation

3. Murray, L. and Hecker, R., "Powering Predictions of a Naval Auxiliary Oiler (AO-177) (Model 5326 with Design Propeller 4645)," NSRDC Report SPD-544-10 (Sep 1974).

4. McCarthy, J. H., "Steady Flow Past Nonuniform Wire Grids," Journal of Fluid Mechanics, Vol. 19, Part 4 (1964).

5. Hansen, B. W. and Rasmussen, R.E.H., "Cavitation Damage Experiments in a Rotating Disk Apparatus Especially with Regard to the Gas Content of Water," Journal of Ship Research, June 1968. pp. 83-87.

TABLE 1

DESIGN DATA PROPELLER 4645

Diameter = 252.000 inches

r/R	Chord Length Inches	c/D	Pitch Inches	P/D	Maximum Thickness Inches	t_m/D	Maximum Camber Inches	C_o/D	Skew Inches	θ_S	Forward Rake Inches
0.2	52.164	0.207	284.256	1.128	10.4328	0.0414	3.0203	0.0120	0.000	0.000	0.0
0.3	58.464	0.232	316.008	1.254	10.3481	0.0411	2.7361	0.0109	-3.077	-2.802	0.598
0.4	62.748	0.249	334.908	1.329	9.7573	0.0387	2.4095	0.0100	-0.257	-0.201	0.036
0.5	64.764	0.257	341.208	1.354	8.6784	0.0344	2.2020	0.0087	8.708	5.999	-0.936
0.6	63.756	0.253	336.420	1.335	7.1726	0.0285	2.2123	0.0088	23.448	14.502	-1.621
0.7	58.958	0.234	315.000	1.250	5.3661	0.0213	2.0049	0.0080	44.263	24.998	-1.042
0.8	49.392	0.196	282.240	1.120	3.4130	0.0135	1.4620	0.0058	65.098	33.799	0.523
0.9	34.776	0.138	241.416	0.958	1.8640	0.0074	0.8312	0.0033	84.421	40.399	2.527
0.95	23.889	0.095	217.192	0.862	1.1995	0.0048	0.5065	0.0020	93.366	42.937	3.792
1.00	0.000	0.000	190.008	0.754	0.000	0.0000	0.000	0.0000	101.769	45.000	5.2[illegible]5

Section Meanline	NACA a = 0.8
Section Thickness Distribution	NACA 66 MOD.
Expanded area ratio	0.734
Projected area ratio	0.590
Mean width ratio	0.211
Blade thickness fraction	0.062
Rake angle	2.402
Projected Skew angle at blade tip	44.999
Linear ratio	25.682

TABLE 2

FAIRED OPEN WATER COEFFICIENTS

PROPELLER 4645

J	K_T	$10K_Q$	η_o
0.000	0.579	0.913	0.000
.050	.561	.890	.050
.100	.544	.869	.100
.150	.527	.849	.148
.200	.511	.830	.196
.250	.494	.812	.242
.300	.477	.794	.287
.350	.460	.777	.330
.400	.443	.760	.371
.450	.426	.742	.411
.500	.408	.724	.449
.550	.390	.705	.484
.600	.372	.686	.518
.650	.353	.665	.549
.700	.334	.643	.578
.750	.314	.620	.604
.800	.293	.595	.627
.850	.271	.567	.647
.900	.249	.538	.663
.950	.226	.506	.674
1.000	.201	.471	.680
1.050	.176	.433	.679
1.100	.150	.393	.668
1.150	.122	.348	.643
1.200	.094	.300	.596
1.250	.064	.249	.509
1.300	.032	.193	.347
1.350	0.000	.133	0.000

```
KT =     .34240                 10KQ =    .65353
        -.26379 (L)                      -.29792 (L)
        -.05491 (L**2)                   -.13386 (L**2)
        -.02754 (L**3)                   -.09541 (L**3)

WHERE  L = ( 1.47605)(J) - 1.0000
```

PROPELLER 4645

Number of Blades	6	Diameter	9.812 in.
Exp. Area Ratio	0.754	Pitch at 0.7 R	12.265 in.
MWR	0.211	Rotation	R.H.
BTF	0.062	Designed by	NSRDC
P/D at 0.7 R	1.250	Reference	P 4645

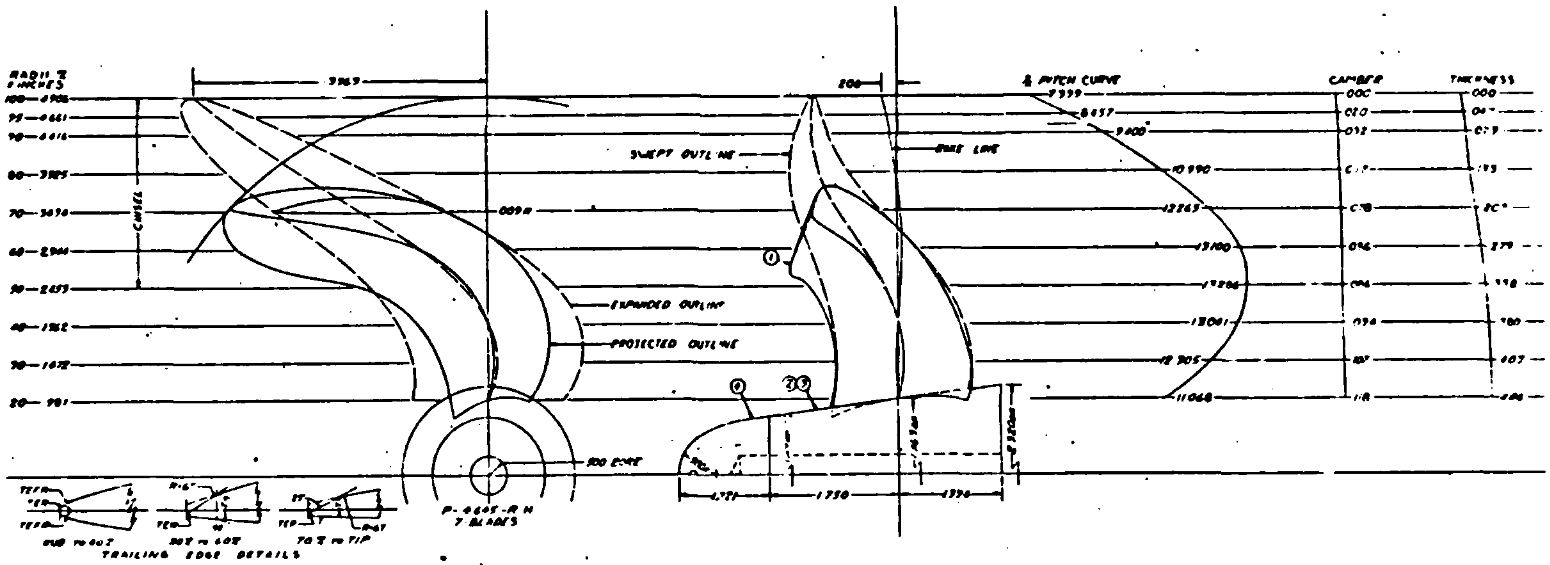
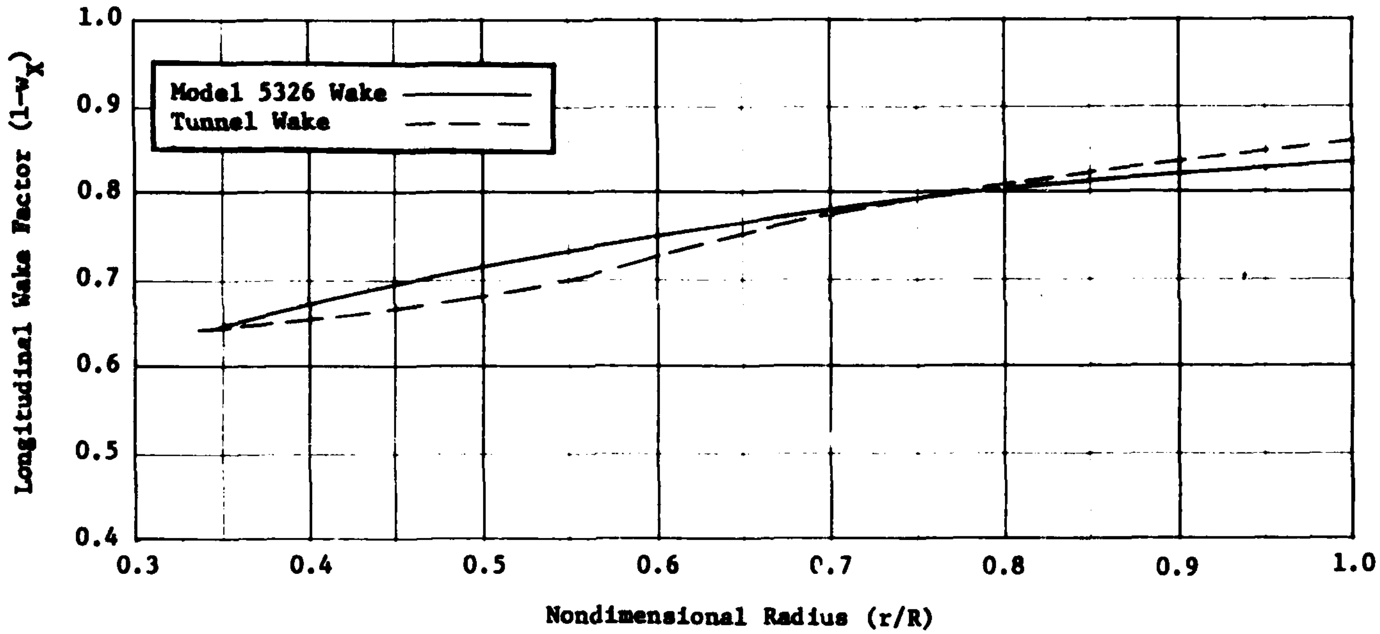


FIGURE 1

AO 177 Auxiliary Oiler
Propeller Diameter 21 Feet



WAKE DISTRIBUTION COMPARISON BETWEEN MODEL 5326
AND 24 INCH WATER TUNNEL WITH WAKE SCREEN

FIGURE 2

SETUP AND TYPICAL CAVITATION

FIGURE 3

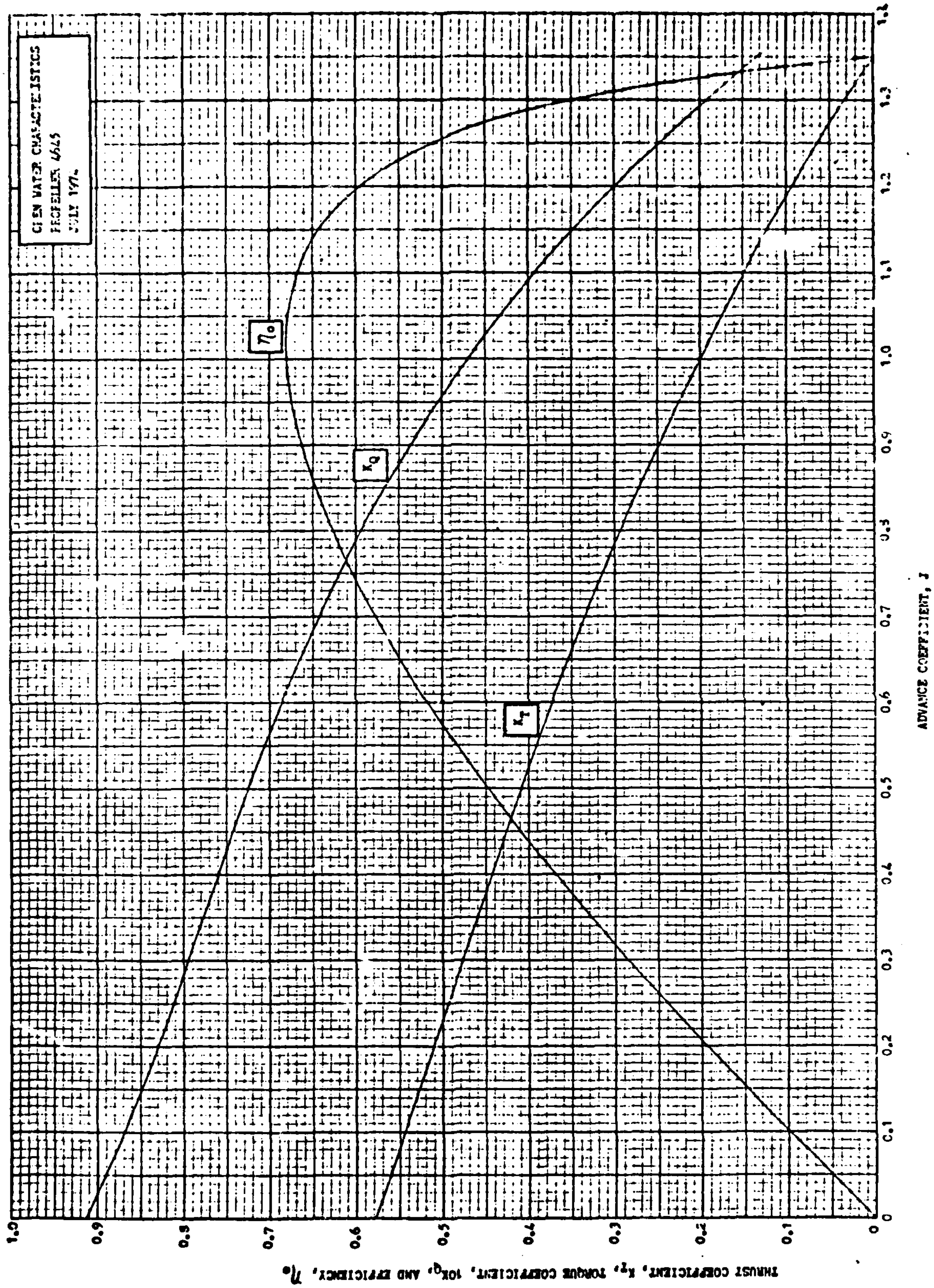

ADVANCE COEFFICIENT, J
THRUST COEFFICIENT, K_T, TORQUE COEFFICIENT, $10K_Q$, AND EFFICIENCY, η_o
η_o
K_Q
K_T

FIGURE 4

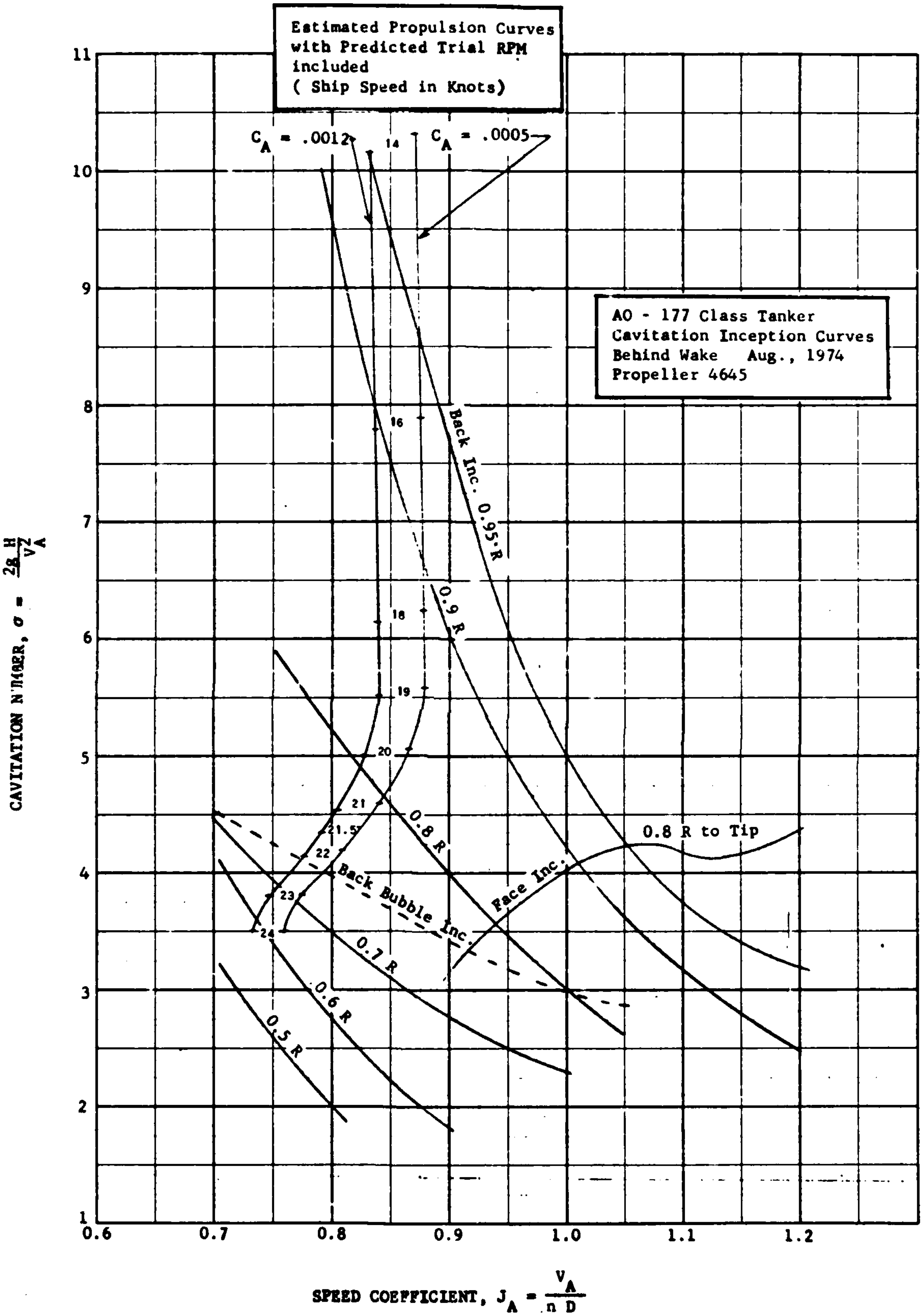
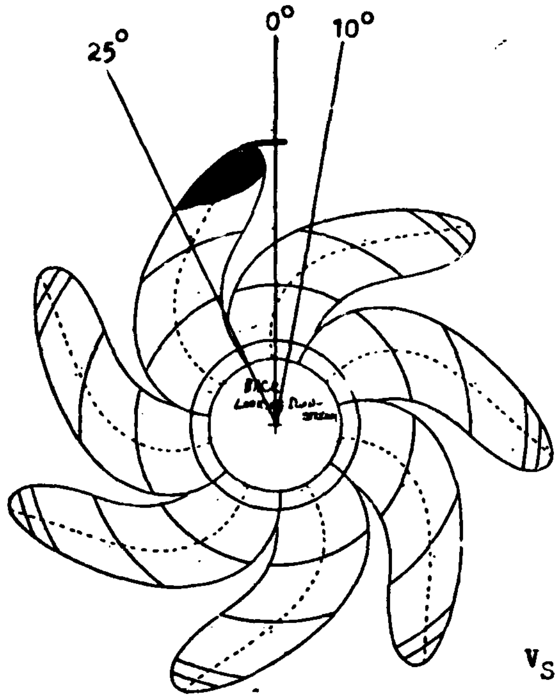
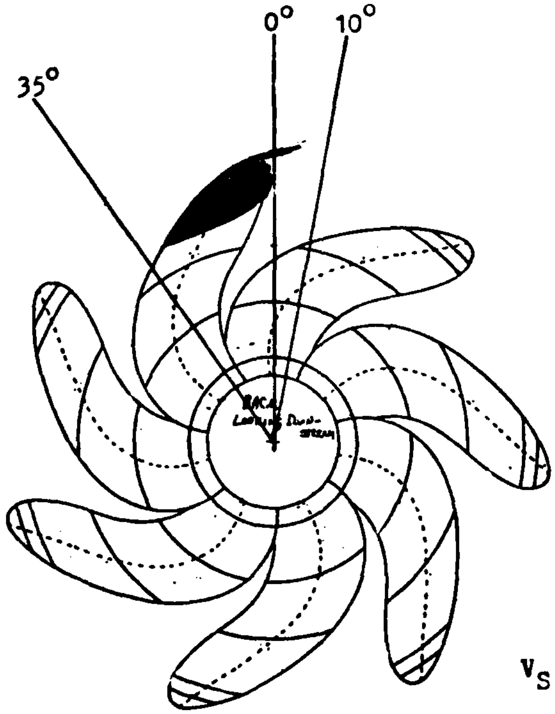

Estimated Propulsion Curves with Predicted Trial RPM included (Ship Speed in Knots)
AO - 177 Class Tanker Cavitation Inception Curves Behind Wake Aug., 1974 Propeller 4645
C_A = .0012
C_A = .0005
14
16
18
19
20
21
21.5
22
23
24
Back Inc. 0.95 R
0.9 R
0.8 R
0.7 R
0.6 R
0.5 R
Back Bubble Inc.
Face Inc.
0.8 R to Tip
11
10
9
8
7
6
5
4
3
2
1
0.6
0.7
0.8
0.9
1.0
1.1
1.2
CAVITATION NUMBER, $\sigma = \frac{2g\ H}{V_A^2}$
SPEED COEFFICIENT, $J_A = \frac{V_A}{n\ D}$

FIGURE 5

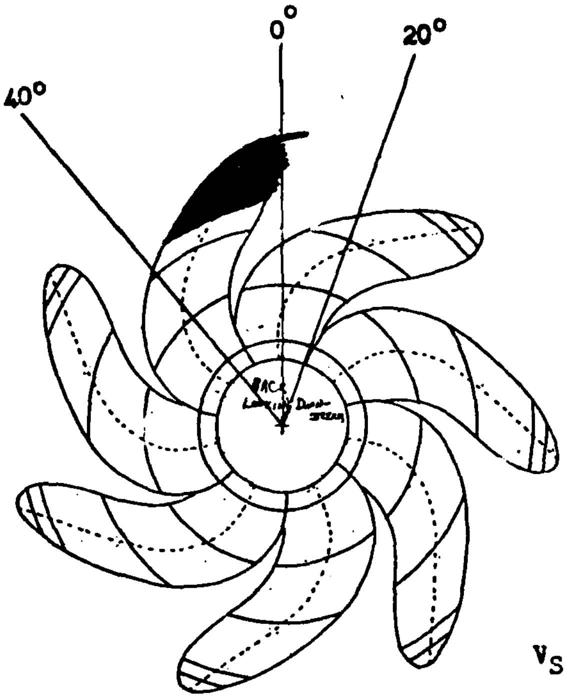


V_S = 20 knots

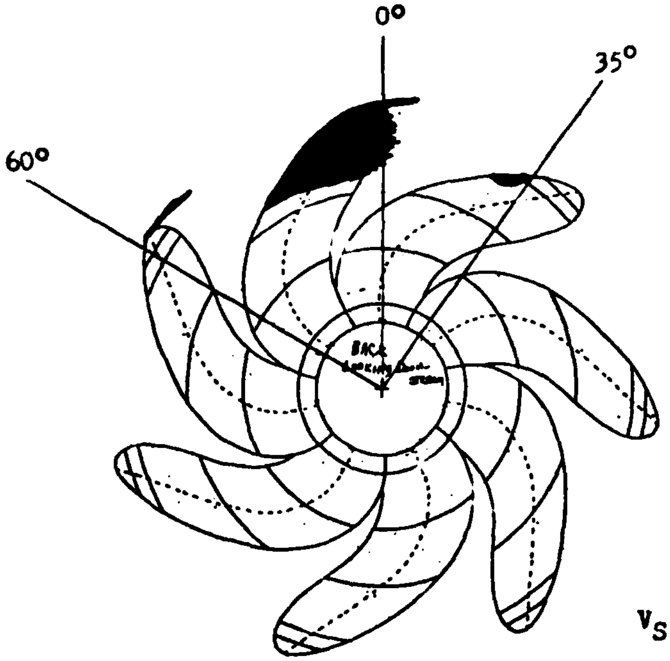


V_S = 21 knots

FIGURE 6

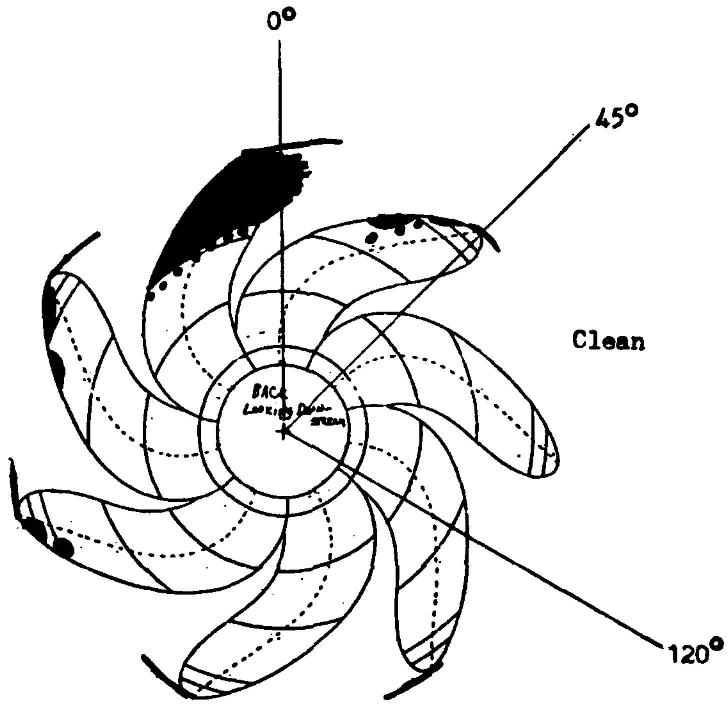


V_S = 21.5 knots



V_S = 22 knots

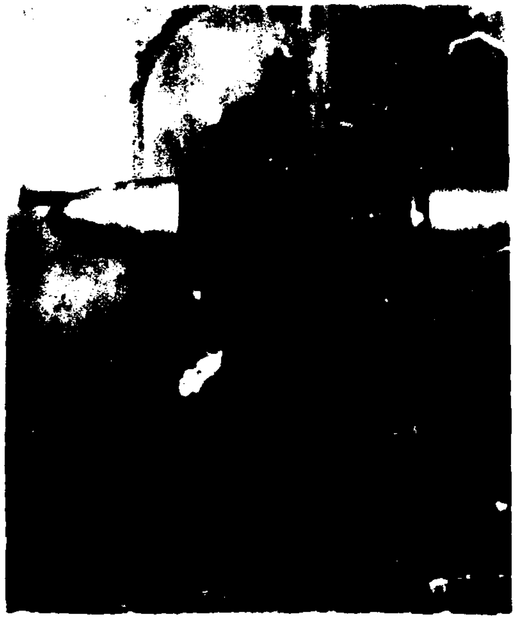
FIGURE 7



Clean

V_S = 23 knots

FIGURE 8



BUBBLE CAVITATION

FACE CAVITATION

FIGURE 9

PSD 341573

19.

FIGURE 10